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# Photon detection by a cryogenic InSb detector

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Gamma rays of  $^{241}\text{Am}$  were measured by a Schottky type undoped InSb detector at 4.2 K. Although a photopeak was not observed, the signals of gamma rays were clearly separated from noises.

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## I. INTRODUCTION

Compound semiconductor InSb has many favorable features as a substrate for radiation detectors: the smallest band-gap energy, 0.165 eV, among developed semiconductor materials, high atomic numbers, In:49, Sb:51, high density,  $5.78 \text{ g cm}^{-3}$ , and high mobilities of electrons and holes,  $78\,000$  and  $750 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$  at 77 K, respectively. The band-gap energy gives us the energy resolution better than that of Ge by a factor of at least two, assuming the Fano factor comparable to that for Ge. The atomic numbers and the density predict 6.5 times higher photon absorption probability than that of Ge, provided that the photon absorption probability is proportional to  $Z^4\rho$ , where,  $Z$  is the atomic number and  $\rho$  the density. The high mobilities of electrons and holes of InSb bring us high efficiency in photon detection: comparing the performance of an InSb detector to a CdTe detector with the same resistivity, thicker depletion layer is expected due to higher mobilities, although photon absorption efficiency of InSb is nearly the same as with that of CdTe. If we could utilize InSb as a substrate for a radiation detector, detection of light elements such as Be and Li becomes possible with measuring characteristic x rays.

McHarris pointed out the advantages of InSb as the substrate of a radiation detector in 1986.<sup>1</sup> There were, however, no activities on radiation detectors made of InSb before our work on the rectifying characteristics of an InSb device.<sup>2</sup>

Recently, we fabricated Schottky type and  $pn$  junction type detectors with  $p$ -InSb, and Schottky type detectors with undoped InSb. They were operated at the temperature from 0.6 to 115 K for the detection of alpha particles of  $^{241}\text{Am}$ .<sup>3,4</sup> Although the depletion layers of these InSb detectors were not thick enough for 5.5 MeV alpha particles to deposit all of their energies, pulse heights due to alpha particles were observed, being clearly separated from electric noises.

As an application of the InSb detector, neutron detection at the operating temperature below 4.2 K was carried out using the nuclear reaction of  $n + {}^3\text{He} \rightarrow p + t$ . The energy spectra of protons (574 keV) and tritons (191 keV) were clearly measured by the undoped InSb detector with the Schottky electrode of 3 mm in diameter.<sup>5</sup>

Our purpose of developing InSb detectors is the detection of photons. In case of measuring gamma rays of  $^{241}\text{Am}$ , 59 keV in energy, we have to reduce the electric noise to 1/10: as described above, the measurements of the protons with 574 keV in energy were successfully carried out. To realize this condition, we fabricated InSb detectors with smaller electrodes to reduce the electric capacitances of them.

In this article, the fabrication method of the InSb detector, the current–voltage curves of it as a function of operating temperature, and the energy spectrum of measured gamma rays are described.

## II. EXPERIMENT

### A. Device fabrication and current–voltage curves

The employed InSb wafer was undoped with diameter of 2 in. and thickness of 0.5 mm (Sumitomo Electric Industries, Japan). This undoped wafer was  $n$ -type by the polarity of preamplifier output pulses in the alpha particle measurements.<sup>6</sup> The wafer was cut to the dimensions of nearly  $5 \text{ mm} \times 7 \text{ mm}$ . Both sides of the InSb substrate were etched using a mixture of nitric and lactic acids (1:10) for 5 min. On one of the InSb substrate surfaces, Au–Pd (60%:40%) alloy was deposited by heat evaporation with a thickness of 4 nm as a Schottky contact. After this process, an electrode area with the diameter of 1.5 mm was defined by a photoresist mask, and the rest of the surface was etched out to fabricate a mesa electrode. The height of the mesa was nearly  $10 \mu\text{m}$ . Finally, the processed wafer was mounted on

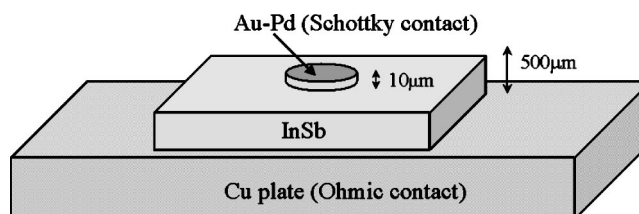


FIG. 1. Schematic drawing of an InSb detector.

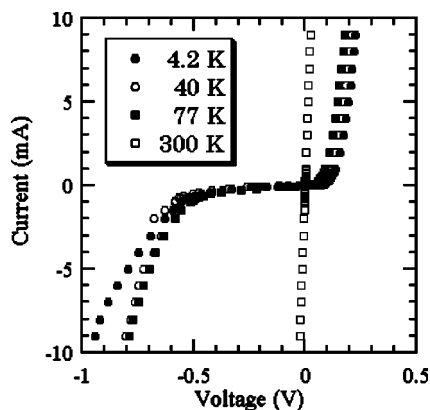


FIG. 2. Current–voltage curves of the InSb detector. The operating temperatures are shown in the figure.

a Cu plate by In solder, having an Ohmic contact on the back surface of the InSb wafer. Figure 1 shows a schematic drawing of the InSb detector.

The fabricated InSb detector was mounted on a probe and inserted into a liquid He dewar for current–voltage ( $I$ – $V$ ) measurements. Measured  $I$ – $V$  curves are shown in Fig. 2 as a function of temperature. The non-linearity of  $I$ – $V$  curve was observed even at 77 K.

### B. Gamma-ray measurement

The InSb detector was mounted on a 0.3 K stage of a refrigerator (Infrared Co.). The InSb detector was exposed by gamma rays of an electrodeposited  $^{241}\text{Am}$  source in the atmosphere through two Be windows on the outer and inner vessels of the refrigerator, respectively.

Figure 3 shows the block diagram of the electronic circuit for the measurements of the gamma rays. The output pulses of a preamplifier and a main amplifier were observed by a digital storage oscilloscope (DSO), and the pulse height spectra were measured by a multichannel analyzer (MCA).

The resistance of the preamplifier was changed from 100 to 2.2 M $\Omega$ , because the resistance of the InSb detector was smaller by some orders of magnitude than the ones of general Si detectors. Measurements were, however, carried out without applying any bias voltage: large electric noises

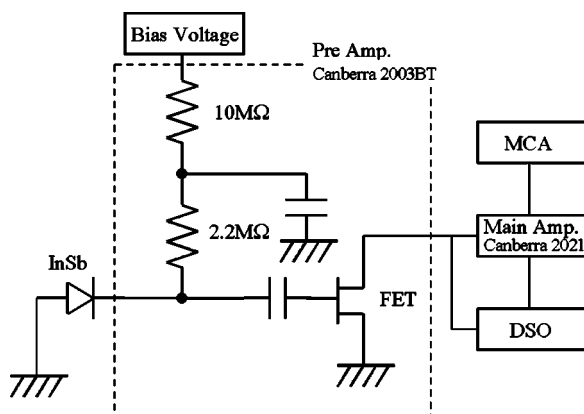


FIG. 3. Block diagram of the electronic circuit for the measurements of gamma rays. DSO: digital storage oscilloscope, MCA: multichannel analyzer.

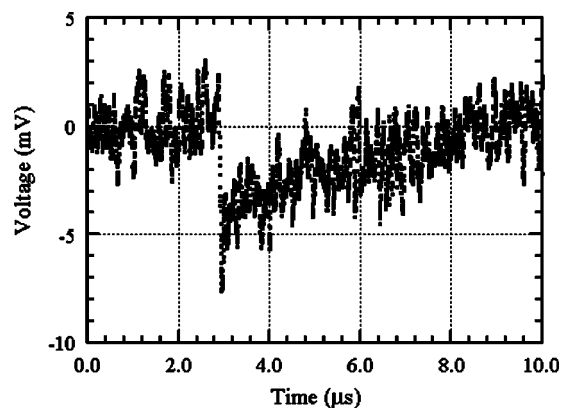


FIG. 4. Preamplifier output pulses of a gamma ray of  $^{241}\text{Am}$ .

were observed when the bias voltage was applied, as was described in the previous papers (Refs. 3–6). Both the foreground and background measurements were performed for 5 min and repeated several times. Measurements were performed at 4.2 K.

### III. DISCUSSION

An example of preamplifier output pulse is shown in Fig. 4. The typical amplitude of the preamplifier output was some mV and 10%–90% rise time was nearly 50 ns. This rise time is shorter than the one of alpha particle measurements in Ref. 6 by one order of magnitude. The energy spectrum of the gamma rays is shown in Fig. 5, as well as the background. Although the photopeak could not be observed, the gamma ray signals were clearly separated from noises. The sources of noise are not studied in detail, however, the leak current of the detector might be the main noise.

In case of the energy of gamma rays being converted into electrons by photoelectric effect, the energy of photoelectrons is almost the same as that of primary gamma rays, i.e., 59 keV. The range of electrons with 59 keV in InSb substrate is estimated as nearly 20  $\mu\text{m}$ .<sup>7</sup> On the other hand, the depletion layer thickness of the undoped InSb detector without applying bias voltage was 9  $\mu\text{m}$ .<sup>6</sup> Most of the photoelectrons escaped from the depletion layer with depositing their energy partly. For the measurement of a photopeak, the

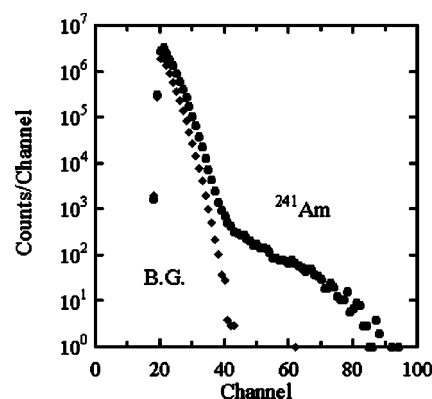


FIG. 5. Measured energy spectra of  $^{241}\text{Am}$  gamma rays and background (BG).

thickness of the depletion layer should be increased. The growth of high quality InSb crystals and the resulting decrease of leak current are necessary.

## ACKNOWLEDGMENTS

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